PB82-247511

Health Effects Associated with Wastewater Treatment and Disposal

(U.S.) Health Effects Research Lab.
Research Triangle Park, NC

Jun 81

U.S. Department of Commerce
National Technical Information Service
NTIS

TECHNICAL REPORT DATA *(Please read Instructions on the reverse before completing)*		
1. REPORT NO. EPA-600/J-81-175	2. JOURNAL ARTICLE	3. RE PB82-247511
4. TITLE AND SUBTITLE Health Effects Associated with Wastewater Treatment and Disposal		5. REPORT DATE 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) N.E. Kowal and H.R. Pahren		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. EPA Health Effects Research Laboratory 26 W. St. Clair St. Cincinnati, OH 45368		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same		13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE EPA-600/11
15. SUPPLEMENTARY NOTES Published in: Journal WPCF 53(6):776-86 (June 1981)		
16. ABSTRACT A review of the literature published in 1980 on health effects associated with wastewater treatment and disposal.		

17. KEY WORDS AND DOCUMENT ANALYSIS		
a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
18. DISTRIBUTION STATEMEI Release to Public REPRODUCED BY NATIONAL TECHNICAL INFORMATION SERVICE U.S. DEPARTMENT OF COMMERCE SPRINGFIELD, VA 22161	19. SECURITY CLASS *(This Report)* Unclassified 20. SECURITY CLASS *(This page)* Unclassified	21. NO. OF PAGES 13 22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

EPA-600/J-81-175
JOURNAL ARTICLE

Health effects associated with wastewater treatment and disposal

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WASTEWATER TREATMENT PLANTS

Haberek[1] briefly reviewed the subject of job safety and health during wastewater treatment and sludge management. Lucas[2] reviewed the nonmicrobiologic contaminants of wastewater aerosols, noting that toxic gases and myriad chemicals, both organic and inorganic, may pose a significant hazard to wastewater treatment workers and potentially to the general public in surrounding areas. Elia *et al.*[3] reported on worker exposure to chlorinated organics at an activated sludge wastewater treatment plant, producing respiratory distress, dizziness, headache, and irritation of eyes, throat, nose, and skin. Kominsky *et al.*[4,5] discussed a municipal wastewater treatment plant that was contaminated with hexachlorocyclopentadiene and related chlorinated hydrocarbons. Plant workers reported irritation of the skin and eyes, sore throat, cough, chest discomfort, headache, nausea, and fatigue with symptoms persisting at least six weeks in 5 to 18% of the workers. Health effects evaluations of 97 workers involved in decontamination procedures showed them to experience similar symptoms; 19% had at least one abnormal liver function test on serial blood testing. The case of a farm worker being asphyxiated by hydrogen sulfide from a liquid manure storage tank was described by Morse *et al.*[6]

Rylander and Lundholm[7] investigated several clinical symptoms among workers at wastewater treatment plants. Because there were high levels of gram-negative bacteria and bacterial endotoxins present in the wastewater plant environment, it was suggested that symptoms were caused by exposure to airborne endotoxins. Clark *et al.*[8] described a prospective seroepidemiologic study applied to municipal wastewater workers and controls in three metropolitan areas: Cincinnati, Ohio, Chicago, Ill., and Memphis, Tenn. The study failed to demonstrate an increased risk of infection in wastewater workers. There was no consistent evidence of increased parasitic, bacterial, or viral infection as indicated by stool examinations, cultures, or antibody surveys. However, there was an increased level of minor gastrointestinal illness among inexperienced wastewater-exposed workers as compared to experienced workers and controls. A one-year multidisciplinary study of the health of wastewater treatment plant workers in two Canadian secondary treatment plants was described by Sekla *et al.*[9] Few significant clinical findings, other than sinusitis, that could be related to the plant were found. In an interim report on a mortality study of former employees of the Metropolitan Sanitary District of Greater Chicago, Gartside *et al.*[10] found that proportionate mortality analyses have not shown any significant departures from expected death rates for several major disease groupings, for the workers as a whole, for several employee subgroups, or by length of employment. Disease rates among Copenhagen sewer workers, who have a higher death rate than a comparable male population, were described by Dean.[11]

Methods for detecting viable microbial aerosols, particularly those formed during processes of wastewater treatment, were discussed by Fannin.[12] Sorber and Sagik[13] consolidated the information available on wastewater microbiological aerosols, identifying organisms of concern that have been isolated from wastewater, presenting, where available, information on their probable survival in aerosols, and evaluating the relative survival rates of pathogens and traditional indicator organisms. Fedorak and Westlake[14] measured airborne bacterial densities

Journal WPCF, Volume 53, Number 6
PGS. 776-786

at an activated sludge treatment plant, and found densities up to 2 600 viable particles/m^3 near sludge sampling taps, and higher counts outdoors near aerated wastewater. Cronholm[15] found elevated levels of aerosolized bacteria downwind of three wastewater treatment plants and a decorative fountain used for wading, and concluded that these sources of aerosolized microorganisms from polluted waters in densely populated areas might be potential health hazards. Wastewater aerosols as a route of infection of humans by pathogens was discussed by Cliver,[16] who concluded that wastewater aerosols are probably relatively inefficient in transmitting enteric infections. Because of concern about the potential public health hazard of microbial aerosols emanating from wastewater treatment aeration tanks, Spendlove *et al.*[17] investigated the effectiveness of aerosol suppression by vegetative barriers, and concluded that strategically placed vegetation would effectively suppress aerosols emanating from wastewater treatment facilities.

The epidemiological approach to disease assessment, particularly with reference to wastewater treatment plants, was discussed by Miday.[18] Camann *et al.*[19] reported the results of the first stage of a potential health hazard investigation: wastewater aerosols and school attendance were monitored at an advanced wastewater treatment plant using the activated sludge process and an adjacent elementary school. The students probably received a peak dose from the aerosol on the order of 2 cfu/m^3 of mycobacteria and 0.8 cfu/m^3 of fecal streptococci. At this level of exposure, the wastewater treatment aerosol had no adverse effect on communicable disease incidence as discerned from total school absenteeism. Acute illness incidence differences with regard to distance from an activated sludge wastewater treatment plant were determined from data obtained as a part of a comprehensive community health study conducted from 1965 to 1971 in Tecumseh, Mich.[20] The data suggest that the higher illness rates are related to higher densities of lower socio-economic families rather than to the wastewater treatment plant. Northrop *et al.*[21] reported on an 8-month environmental health study carried out in a 1.6 km area surrounding a 202 mgd activated sludge plant. No remarkable correlations were found between the exposure indices and rate of self-reported illnesses or of bacterial or viral infection rates determined by laboratory analysis. However, the plant was identified as a source of viable particles and total coliforms. The overall conclusion that this activated sludge treatment plant had no obvious adverse health effect on residents potentially exposed to aerosol emissions must be tempered by the very small number of people who were exposed to the highest pollution levels. Johnson *et al.*[22] described a study to identify the hazard to public health of aerosols emanating from wastewater treatment plants by examining a new activated sludge facility. Environmental monitoring, household health surveys, and assays of clinical specimens from human subjects were conducted during four baseline and operational sampling periods within a 5 km radius of the plant. The residential area began 350 m from the plant. It was concluded that, at the exposure levels investigated, the wastewater treatment aerosols from well-operated American plants do not appear to be a significant health hazard to residential populations, and that current evidence is insufficient to determine whether effects of lesser consequence, such as gastrointestinal symptoms and skin conditions, are associated with moderate aerosol exposure.

Because of the concern that antibiotic resistance factors (R plasmids) in coliforms are being transferred to enteric bacterial pathogens in wastewater, environmental waters, or individuals who harbor such coliforms previously ingested in the course of water-associated activities, some investigators have suggested the need for more stringent water quality standards limiting the densities of coliforms in environmental waters and for more advanced purification of wastewater prior to its discharge into the environment. To address this issue, Shaw and Cabelli[23] isolated multiple-drug-resistant strains of *Escherichia coli*, representing about 8.3% of the total *E. coli* population, from the water at an estuarine site, and measured the R-plasmid tranfer frequencies to laboratory and fecal strains of *E. coli*. It has been estimated that an individual swimming in barely acceptable waters may accidentally ingest between one and five R^+ coliforms. About 60% of R^+ strains did possess conjugative R plasmids; however, the majority of these strains transferred their plasmids at frequencies of 10^{-4} or less per donor cell. Therefore, the likelihood that one out of one to five ingested *E. coli* will donate its resistance to the fecal flora becomes minimal, especially since fecal strains are generally poor recipients. The authors concluded that because of the current standards for permissible coliform levels at bathing beaches, the low frequency of piliated cells, the concentrations required for colonization, and the rarity of plasmid transfer in the human alimentary tract, the "health risk" to swimmers posed by R-plasmid-bearing coliforms does not seem to be great. Bell *et al.*[24] examined the incidence of R factors (or plasmids) for antibiotic resistance in coliform, fecal coliform, and *Salmonella* bacteria of the Red River in Canada. It was calculated that populations of fecal coliforms containing R factors were as high as 1 400 per 100 ml and that an accidental intake of a few milliliters of water could lead to transient or permanent colonization of the digestive tract. They concluded that a reevaluation of water quality standards should take R factors, and their clinical consequences, into consideration. In related work, Ishiguro *et al.*[25] found that transmission of R plasmids between naturally occuring strains of *Salmonella* and *E. coli* probably occurred at pig farms. These reports may be viewed in the context of recent documentation of the increase in antimicrobial resistance among isolates of *Salmonella* in the U. S. from 1967 to 1975.[26]

Hutzler and Boyle[27] reviewed the hazards associated with wastewater discharges, suggested a basis for assessing the risks of contracting disease as the direct result of wastewater discharges, and demonstrated their risk assessment methodology by estimating the disease risk of hepatitis A virus discharge. Cabelli[28] reported the results of several prospective epidemiological studies relating the incidence of gastrointestinal disease to degree of wastewater pollution at several marine beaches. He used the results to derive health effects quality criteria for marine recreational waters and a recommendation for a specific criterion among those developed. This was the mathematical relationship of the swimming-associated rate of gastrointestinal symptoms among bathers to the quality of the water as determined by the density of a fecal indicator, enterococci. Such a criterion can be used to provide guidelines based upon acceptable rather than detectable risk and is consistent with risk analysis.

COMPOSTING

The dispersal of *Aspergillus fumigatus* from wastewater sludge compost piles subjected to mechanical agitation by

front-end loaders was studied by Millner *et al.*[29] Aerosols of *A. fumigatus* downwind from stationary compost piles were insignificant in comparison with those downwind from agitated piles. The maximum emission rate, 4.6×10^6 *A. fumigatus* particles per second, was used to calculate predicted concentrations in an unobstructed plume with restrictive, neutral, and dispersive atmospheric mixing conditions up to 1 km downwind from the emission source. Burge and Millner[30] reviewed the primary and secondary pathogens, as well as allergenic microorganisms and substrates, encountered during the composting of wastewater sludge, and the hazards to both on-site and off-site people. They recommended measures for protection against *A. fumigatus* and thermophilic actinomycetes. The results of long-term monitoring of municipal sludge composting operations in Maine for *A. fumigatus* spores were presented.[31] Chronic increases in numbers of ambient *A. fumigatus* aerospora did not occur; short-term increases, rapidly rising and falling, were associated with specific operations, such as woodchip manipulations. Potential health effects were reviewed and were concluded to be unlikely. However, some basic precautions were recommended: prospective workers should be given physical examinations; personnel with histories of allergic sensitivity, recent renal or cardiac disease, or immunosuppressive therapy should not be employed in composting operations; front-end loaders should be equipped with enclosed air conditioned cabs or operators should wear dust-filtering masks; and plants should not be sited in the vicinity of hospitals or nursing homes. These measures should minimize the risk of increased aspergillosis incidence as a result of composting operations.

Lundholm and Rylander[32] described subjective symptoms (nausea, headache, and diarrhea), among workers in an experimental compost plant, resulting from airborne gram-negative bacteria from household solid waste. The potential health effects of exposure to microbial agents associated with the composting of municipal wastewater sludge were reviewed by Clark *et al.*[33] Two agents of particular concern were the fungus, *A. fumigatus*, and endotoxin, from the large numbers of gram-negative bacteria in sludge. The preliminary data on antibody response of the compost workers at the Beltsville-Blue Plains sites to endotoxin suggest that to reduce exposure it may be advisable to take reasonable precautions such as the use of respirators by compost workers and periodic water spraying of the compost sites to reduce dust.

LAND APPLICATION OF WASTEWATER AND SLUDGE

The results of a varied research program on the health effects in cattle, swine, and poultry fed sludge-amended-soil-grown feed or sludge, and in mice fed liver and kidney from these animals, were summarized by Edds *et al.*[34] The effects of toxic chemicals, both trace elements and organics, present in wastewater sludge on animal health were reviewed by Kienholz.[35] Special emphasis was made on exposure through direct consumption of sludge by animals. Baxter *et al.*[36] reported on a study initiated to examine effects of wastewater sludge disposal on agricultural land and possible transmission of sludge contaminants into the food chain. Soils, forages, and cattle grazing at a wastewater sludge disposal site were examined for trace metals and refractory organics content. Sludge feeding studies showed that sludge had no positive or negative effects on animal health or performance other than to act as a diet diluent. These studies showed that metal or organic uptake into cattle tissues is in proportion to the contaminant level of the sludge. It was concluded that if wastewater sludge is utilized as an agricultural fertilizer and incorporated into the soil, there would appear to be little hazard that metals or organics would be elevated above levels considered normal. Fitzgerald[37] exposed pigs to municipal sludge in pens and found transmission of *Ascaris* from liquid anaerobically digested sludge, that had been stored for several years, as well as from dried stored sludge. The accumulation of trace elements and toxic organics was also investigated; only an increased uptake of cadmium was found, with no physiological or pathological conditions.

The long-term effects of the land application of secondary effluents at Mesa, Ariz., were examined; after more than 16 years of continuous land application no adverse health effects were reported from farm workers, consumers, or wastewater treatment plant personnel.[38] Uiga and Crites,[39] comparing the potential health effects of activated sludge and land treatment systems, concluded that both treatment systems are effective in minimizing health risks, and that land treatment systems provide equal or greater removal of various wastewater constituents. A brief overview of the health risks of land application of sludge was provided by Pahren.[40] The public health risks of the land application of wastewater sludge because of trace elements and pathogens were extensively reviewed from the British viewpoint by Hudson and Fennel.[41] It was concluded that by careful choice of sites and by exercising sensible control based on scientific facts, both chemical and microbiological risks could be reduced to a minimum.

The Del Monte Corporation's decision not to accept crops grown on sludge-amended soil, and the reactions of the U. S. Environmental Protection Agency (EPA) and Food & Drug Administration (FDA) were briefly reviewed.[42] The regulatory aspects of sludge application to land were discussed by Robens,[43] who felt that the FDA would have serious questions concerning the practice of direct feeding to animals. Newkumet[44] summarized the status of EPA's forthcoming regulations governing the public distribution and marketing of wastewater sludge-derived fertilizer products.

Parasites, bacteria, viruses. Johnson *et al.*[45] evaluated microbiological aerosols produced during land spraying of unchlorinated secondary effluent. It was concluded that the use of the traditional indicator organisms to predict population exposure results in extreme underestimation of pathogen levels; that large-volume samples (1 m^3/min) are most useful for obtaining bacterial aerosol data; that heroic efforts are required for sampling enterovirus aerosols; and that the use of a dispersion model to predict aerosol concentrations is an economic and viable alternative to extensive aerosol monitoring. Such a model was described in the report. Teltsch *et al.*[46] isolated and identified pathogenic microorganisms in aerosols at land treatment sites in Israel, finding *Salmonella* at 40 m and enteroviruses at up to 100 m from the source. From the ratios of salmonellae to coliforms and enteroviruses to coliforms in the air, as compared to these ratios in the wastewater, it was concluded that the suitability of coliforms as an indi-

ganisms were estimated in three domestic wastewater sludges, and the potential impact of land application of wastewater sludges was discussed.

The clinical features, pathogenesis, bacteriology, and epidemiology of *Campylobacter jejuni* and *Yersinia enterocolitica*, and new epidemiological findings in the field of salmonellosis and shigellosis, were reviewed by a WHO Scientific Working Group.[70] The vehicles and modes of transmission of *Campylobacter fetus* spp. *jejuni* infection to humans was reviewed by Blaser.[71] *Campylobacter* is now isolated as commonly as *Salmonella* and *Shigella* from patients with diarrhea, and the principal means of infection appear to be fecal-oral spread and food-borne and waterborne transmission.

The bacterial causes of diarrhea in Sweden were recently surveyed, and the results showed 10.9% of the cases to be caused by *Campylobacter*, 7.2% by *Salmonella*, 3.5% by *Shigella*, and 0.7% by *Yersinia*.[72] This provides further documentation of *Campylobacter fetus* spp. *jejuni* as a major cause of bacterial diarrhea. Jones *et al.*[73] examined British wastewaters and sludges for *Salmonella* to evaluate the significance of land application to animal health. It was found that samples usually contained less than 200 salmonellas/100 ml, and concluded that these concentrations should not lead to disease in animals if suitable grazing restrictions are followed, that is prevention of grazing for 4 weeks after latest application. Ayanwale *et al.*[74] raised goats on corn silage grown on sludge-amended land, and found no *Salmonella* infections in spite of the presence of *Salmonella* in the sludge, supporting the position that the potential public health hazard resulting from the use of sludge as fertilizer when properly treated has so far proven not to be a threat. The subject of *Shigella* infections was reviewed by Keusch,[75] who indicated that the disease is readily spread by contact because so few organisms (10 to 100) are required to establish infection. It may also be spread through contaminated food or water, related to either defective wastewater or a human carrier, and explosive outbreaks may occur in closed populations. A WHO Scientific Working Group[76] reviewed the subject of *Escherichia coli* diarrhea. Three groups are important as diarrheal pathogens: enterotoxigenic *E. coli* that produce enterotoxins are important causes of diarrhea in infants, young children, and adults in developing countries, and also in travellers to these countries; enteropathogenic *E. coli* that have been responsible for frequent outbreaks in infantile diarrhea in many parts of the world, especially in the period from the late 1940s to the early 1960s; and enteroinvasive *E. coli* that are invasive and have a pathological behavior similar to that of *Shigella*. Levine *et al.*[77] studied the mechanism of transmission of enterotoxigenic *E. coli*, concluding that direct person-to-person contact among healthy adults played little role, and that fecally contaminated food and water probably were the major means of spread. This is probably because relatively large inocula, 10^6–10^{10} organisms, are required to induce diarrhea. The identification and characterization of enterotoxigenic *E. coli* were reviewed by Sack,[78] who thought it feasible that live *E. coli* vaccines that would contain the appropriate virulence factors necessary for broad-spectrum protection could be devised.

The September–October 1978 outbreak of cholera in southwestern Louisiana was reviewed, and it was concluded that all 11 persons were infected by consumption of cooked crabs from Louisiana marshes.[79] All isolates in Louisiana, and an isolate from a single unexplained case in Texas in 1973, were biotype El Tor and serotype Inaba; they were hemolytic and of a phage type unique to the U. S. suggesting that the organism had persisted undetected along the Gulf Coast for at least five years. In a further discussion of this outbreak the history of cholera was concisely summarized, and the possibility explored that pathogenic strains of *Vibrio cholerae* may adapt to a free-living form and exist in the environment.[80] The first case of cholera in the U. S. since 1978 was reported in November 1980 in Florida, the infection probably coming from oysters.[81]

In the period 1974–1978, 498 cases of leptospirosis were reported to the CDC in the U. S., with a distinct seasonal predominance in the months of July–October.[82] Water was the most common single source of infection, and sewer workers, farmers, and abattoir workers had the highest risk. Goyal *et al.*[83] raised the possibility of bacterial endotoxin getting into groundwater as a result of land treatment. They found that 90 to 99% of endotoxin in wastewater was removed after travel through 100 to 250 cm of loamy sand soil, but that the removed endotoxin could be mobilized by distilled water. On testing samples from actual land treatment sites, as much as 480 ng of endotoxin per milliliter was found in some groundwater samples; the presence of endotoxin in potable water is known to be a potential problem under some circumstances, but the importance of endotoxin in water supplies has not been fully assessed.

A comprehensive textbook of experimental virology by Bitton[84] extensively discussed the areas of wastewater, sludge, and land application, in addition to more traditional areas. A WHO Scientific Group[85] produced a report on human viruses in water, wastewater, and soil. Discussed were the human viruses in polluted water, minimum infective dose of ingested viruses, limits of epidemiological investigations, sources of infection, virus monitoring, virus removal by treatment processes, natural recycling and intentional reclamation of water, and conclusions and recommendations. Bitton and Farrah[86] briefly reviewed the viral aspects of land application of sludge, and concluded that enteroviruses are efficiently retained by the sludge-soil matrix. Association with sludge solids would help to restrict their movement through soils, and viruses are significantly inactivated in soils under warm and dry conditions. It was stressed that these conclusions are currently valid only for the enteroviruses group, and methodology for the study of the behavior of other enteric viral causes of gastroenteritis, especially rotaviruses, has yet to be developed. Keswick and Gerba[87] reviewed the factors affecting the entry, survival, and migration of viruses in ground water, along with research needs. The epidemiology, clinical features, and laboratory diagnosis of acute diarrhea resulting from rotavirus and Norwalk-like agents were reviewed in detail by a WHO Scientific Working Group.[88] Other possible viral causes of acute diarrhea, that is, adenovirus, astrovirus, calicivirus, coronavirus, enterovirus, and other small, round, virus-like objects (SRVs), were also described. Research priorities were also recommended, the foremost of which being the development of a rotavirus vaccine for use in man. The oral infectious dose (OID) of enterovirus in pigs—animals with digestive tracts similar to those of humans—was studied by Cliver.[89] It was

cation of airborne contamination caused by spray irrigation is questionable. Camann[47] presented a dispersion model framework for predicting the viable airborne concentrations of specific microorganisms dispersing from a nearby source of wastewater aerosols. Estimates and estimation procedures for key model parameters, such as the viability decay rate, were developed from field monitoring data. In the specific model applicable to spray irrigation, model parameters representing aerosolization efficiency and the initial aerosol impact effect on microorganisms were also evaluated. The procedure for predicting downwind microorganism levels was illustrated using several examples. The applicability of the model to estimating the dose of microorganisms inhaled by humans in the vicinity of a wastewater aerosol source was considered. Disease transmission by wild animals from sludge-amended land was discussed by Prestwood.[48] Yeager[49] provided a comprehensive review of the risk to animal health from pathogens in municipal sludge, emphasizing the risk to animals grazing on sludge-treated pastureland. Although the risk was thought to be small, potential organisms of concern were *Taenia saginata* (beef tapeworm), *Mycobacterium* (tuberculosis), *Salmonella*, enteropathogenic *Escherichia coli*, and viruses. The survival of fecal coliforms and coliphage on pasture grass following applications of liquid digested sludge was investigated by Brown *et al.*[50] It was found that the coliphage decreased rapidly with drying time, with none detected 48 hours after application. Fecal coliforms survived for 2 to 3 weeks, with rainfall having little influence on length of survival.

The factors that govern safety of applying sludges to agricultural crops, from the standpoint of human pathogens potentially transmissible through foods, were reviewed by Cliver.[51] Sagik *et al.*[52] provided a comprehensive overview of the health risks associated with bacteria and viruses in land application of municipal sludge. In 1978, 32 outbreaks of acute waterborne disease involving 11 435 cases were reported to the Center for Disease Control (CDC) and EPA.[53] Of those outbreaks for which the etiology was determined, *Shigella* accounted for 4, *Giardia lamblia* for 4, parvovirus-like agents for 3, *Salmonella* for 2, chemicals for 2, and *Campylobacter fetus* subspecies *jejuni* for 1. Untreated groundwater was responsible for 10 outbreaks with 1 471 cases. CDC[54] published its annual summary of 1978 water-related disease outbreaks. Katzenelson *et al.*[55] reported the results of an early study on the incidence of enteric communicable diseases in 77 kibbutzim (agricultural communal settlements) practicing wastewater spray irrigation, plus 130 controls (all in Israel), finding the incidence of shigellosis, salmonellosis, typhoid fever, and infectious hepatitis to be 2 to 4 times higher in the 77 kibbutzim. Progress on a follow-up study was reported by Shuval and Fattal.[56] From 1977 to 1979 the epidemiological study was carried out in Israel on the association between enteric disease incidence and effluent irrigation in 83 kibbutzim with a total population of 41 000. The results were analyzed according to the age groups of the population, the irrigation season, and other environmental factors. Inspection of overall incidence of enteric disease incidence did not appear to show evidence of association between the effluent and noneffluent irrigation years at the same kibbutzim. In an analysis of various environmental factors, in no case was there any apparent difference between effluent-irrigating and noneffluent-irrigating kibbutzim. The analysis was incomplete at the time of the report, however, so that no final conclusions could be drawn.

The effectiveness of gamma irradiation in killing pathogens in sludge was discussed by Yeager and Ward,[57] who concluded that a dosage of 1 Mrad is capable, by itself, of eliminating bacterial, fungal, and parasitic pathogens. Viruses require another process in conjunction with gamma irradiation. An EPA viewpoint on disease control requirements for various types of sludge users was presented by Tonetti.[58] Young[59] compared cost estimates of alternatives for controlling the spread of disease organisms in aerosols from municipal spray irrigation systems. When chlorination provides a sufficient level of disinfection, it appeared to be the least-cost alternative. Two alternatives, substitution of surface for spray irrigation when surface terrain permits and the use of buffer zones when land costs are low, were also likely to be cost effective.

Little[60] provided a comprehensive discussion of parasites likely to be found in municipal sludges and briefly evaluated the associated health risks. Macpherson *et al.*[61] briefly reported on an outbreak of cysticercosis, from the tapeworm *Taenia saginata*, in cattle grazing on land to which wastewater sludge had been applied. The protozoan pathogen, *Giardia*, and the disease it causes, giardiasis, were reviewed by Meyer and Jarroll[62]; areas covered were taxonomy, life cycle, geographic distribution, symptoms of disease, diagnosis, drug therapy, immunology, transmission, and prevention. Several recent reports exemplified the increasing frequency with which *Giardia* is being implicated as the cause of waterborne outbreaks of diarrhea.[63] These and past outbreaks have several features in common, namely that they occur in communities where surface water (streams, rivers, lakes), not well water, is used, chlorination is the principal method for disinfecting water, and water treatment does not include filtration, or existing filters have structural or operational defects. Methods for treating contaminated water were also discussed. The contamination of surface water supplied by *Giardia* cysts was briefly reviewed, and the importance of continuous, adequate filtration as the key to prevention of waterborne giardiasis was emphasized.[64] The first documented outbreak of foodborne giardiasis was reported by Osterholm *et al.*,[65] although the fecal-oral route of transmission has long been well established.

Teltsch *et al.*[66] presented a methodology for estimating, under field conditions, the microbial die-away constant of aerosolized bacterial from sprinkler application of wastewater. Mutlack *et al.*[67] described the gross bacterial contamination of soil and lettuce at a raw wastewater-irrigated farm in Iraq, warning of the public health threat of the common practice of growing vegetables by this means in that country, and noting that *Salmonella* could be found on lettuce for one week after application, but not afterwards. The physico-chemical and bacteriological characteristics of well water at 2 wastewater farms in India were examined.[68] The wells were open dug, and used for domestic purposes by the local inhabitants; they were found to be highly polluted with fecal coliforms and fecal streptococci, and unfit for drinking and domestic purposes. To ascertain the health risks that may be posed by the land application of wastewater sludges, a scheme was derived by Dudley *et al.*[69] to determine the types and numbers of pathogenic and potentially pathogenic bacteria present in sludges. Utilizing the proposed scheme, the population densities of these or-

found that a given quantity of enterovirus is more likely to produce an infection if inoculated into a susceptible tissue culture than if ingested by a potential host organism with drinking water. The OID for waterborne enterovirus ingested by susceptible young pigs was calculated, with the aid of the Poisson formula, to be approximately 1 800 to 2 500 plaque forming units (PFU) of porcine enterovirus Type 3 and 600 to 750 PFU of Type 7. Even though both strains of virus used in this study were purportedly virulent, no perceptible illness resulted from the virus infections produced with dosages up to 10^4 PFU.

Non-polio enterovirus disease in the U. S. for the years 1971–1975 was reviewed by Morens *et al.*[90] During this period, 7 075 cases were reported to CDC, including diagnoses of aseptic meningitis, encephalitis, upper respiratory tract disease, non-specific febrile illness, gastroenteritis, pneumonia and lower respiratory tract disease, exanthem, and enanthem. Enteroviral disease occurred most commonly in children during the summer months, with no significant geographic differences observed. Phillips *et al.*[91] reviewed diseases caused by enteroviruses in Vermont for the years 1969–1978, emphasizing that disease occurs not only during the peak months of July–October, but also throughout the year. Among these diseases were aseptic meningitis, hand-food-and-mouth disease, diarrhea, pleurodynia, myocarditis, herpangina, and fevers. On the basis of an extensive outbreak of gastro-intestinal illness from wastewater contaminated water at Crater Lake National Park, Rosenberg *et al.*[92] calculated that the hepatitis A attack rate among persons who drank the contaminated water was 920/100 000 per year, whereas the normal incidence of hepatitis A is about 100/100 000 per year. On the basis of an economic analysis, the authors did not recommend routine prophylactic immune serum globulin for outbreaks of gastroenteritis caused by wastewater-contaminated water.

Organics. The toxic organic residues potentially in sludge, and their possible human health effects, were reviewed by Dacre.[93] Organohalogen pesticides and polynuclear aromatic hydrocarbons were regarded as particularly threatening. Baker *et al.*[94] described the metabolic consequences of exposure to polychlorinated biphenyls (PCB) from contaminated wastewater sludge used as a soil amendment in Bloomington, Ind. No skin or systemic symptoms were noted, and of the hematologic, hepatic, and renal functions measured, only serum triglyceride levels increased, suggesting altered lipid metabolism. Serum PCB levels were normal. Stich *et al.*[95] found fecal extracts from carnivorous and herbivorous animals to produce dose-related chromosomal mutations in cultured mammalian cells, and raised the possibility that mutagens and carcinogens of animal and human fecal origin may enter and persist in our water system.

Inorganics. Sterritt and Lester[96] reviewed the effects of organic matter, nitrogen, phosphorus, and toxic elements in wastewater sludges applied to agricultural land, with emphasis on the factors that influence the forms of toxic trace elements, their long-term availability, and their accumulation by crops. Sommers[97] reviewed the toxic trace elements present in sludges, their fate in soil-plant systems, uptake by agricultural crops, and current guidelines for application of sludge on cropland. Chaney[98] reviewed the trace elements in sludge, their transfer to the food chain upon land application, interaction with each other and with other dietary constituents, and the potential for human health effects from sludge-borne cadmium. He concluded that it seems increasingly likely that low-risk systems can be developed for utilization of the beneficial aspects of sludge.

Cadmium's chemistry, biochemistry, and biology has recently been reviewed in detail in an extensive, multi-author text,[99] including a chapter on cadmium in man. The environmental flow of cadmium in the U. S. was surveyed by Yost,[100] who concluded that, with some local exceptions, there is little evidence to suggest that on a national scale, man's activities have resulted in either significant cadmium ecological effects or in a meaningful increase in human cadmium intake in the U. S. Potential exceptions to this conclusion are the applications of metal-contaminated digested wastewater sludge and/or high cadmium rock phosphate fertilizers to crop land. The sludge problem could in large part have been obviated by imposition of currently available control measures that remove approximately 95% of heavy metals from aqueous water streams. The available data on the effects on plants of single and repeated additions of cadmium and zinc to soils in the form of wastewater sludge were evaluated in a new CAST report.[101] The absorption, distribution, and excretion of cadmium in experimental mammals was reviewed by Probst.[102] Heffron *et al.*[103] fed sheep corn silage grown on soil amended with municipal sludge at high rates, and found elevated cadmium and zinc levels in kidney and liver but not in muscle tissue. Histopathologic changes in hepatic sections of the sheep fed sludge-grown corn silage were also observed by electron microscopy. It was speculated that the high zinc content of the organs might exert a protective effect if consumed as food. Fitzgerald[104] reported on the health of animals exposed to anaerobically digested sludge from Chicago, finding increased cadmium and lead levels but few clinical or histological effects.

Recent progress in cadmium health effects studies were reviewed by Nomiyama.[105] The biochemical and pharmacological effects of cadmium were reviewed by Singhal and Merali.[106] Exposure to cadmium can alter several vital metabolic processes in various organ systems, and several manifestations of cadmium toxicity can be prevented if selenium, zinc, or certain other elements are administered either prior to or concurrently with cadmium. Hallenbeck[107] estimated the dietary increase of cadmium derived from crops grown on sludge-amended soils, and concluded that a diet derived completely from sludge-amended soils would very likely be excessive in cadmium. Borman[108] briefly described Brookhaven National Laboratory's neutron activation analysis method of measuring cadmium in the liver and kidney of living subjects. The carcinogenic potential of cadmium was reviewed by Malcolm,[109] who concluded that in general use and in industrial exposure a somewhat tenuous association between cadmium exposure and carcinoma exists. Firm evidence is lacking and the importance of careful follow-up was stressed. With reference to the possible carcinogenicity of cadmium, a controversial question today, Löser[110] performed a two-year feeding study on rats, using cadmium Cl_2. Cadmium administered orally was not associated with an increased incidence of total numbers of tumors or of any specific type of neoplasia, although the highest level tested resulted in adverse effects. Rohrer *et al.*[111] reviewed cadmium teratogenesis, the relation of zinc and other

factors to cadmium-induced fetotoxicity, the placental transfer of cadmium, and the presence of cadmium in human fetal tissues. The cardiovascular and renal effects of cadmium were reviewed by Bousquet,[112] who concluded that human and animal data currently available suggest a correlation between cadmium and hypertension, but that any stronger statement associating the two in a cause-and-effect manner is unjustified at this time.

Lue-Hing *et al.*[113] claimed that the proposed EPA solid waste disposal regulations would limit the sludge land application programs of the Metropolitan Sanitary District of Greater Chicago, as well as those of many other wastewater agencies. They felt that limitations on cadmium present a difficult problem, because only about 38% of cadmium loading to the district treatment plants originates in industry, and thus could be controlled at its source.

Adam[114] reviewed the literature on the health aspects of nitrate in drinking water, and concluded that it justified a limit of 10 mg N/l. On the basis of 30 years of well records in a densely populated river basin, DeWalle and Schaff[115] detected gradually increasing levels of nitrate in ground water, a potential cause of methemoglobinemia in infants, and attributed the increase to septic tank drainfields.

RENOVATED WATER

Miller[116] briefly described Denver's planned 4.4×10^{-2} m^3/s (1.0 mgd) potable-water reuse demonstration plant. McCarty[117] stated that there is an urgent need to conduct the kind of research necessary to evaluate the safety of reclaimed municipal wastewaters and to develop criteria, if possible, by which the health risks and reliability of treatment processes for reclamation for this purpose can be judged. Research programs of the EPA Health Effects Research Laboratory (Cincinnati) relating to potential health effects associated with consumption of renovated water were discussed by Pahren.[118] Research carried out to date has emphasized the organics and toxicology areas. Other areas receiving attention are microbiology, inorganics, and criteria for renovated water. Johnson[119] pointed out that every community water treatment plant that exists below the discharge of a wastewater treatment plant is in the mode of unplanned reuse. Although additional information is needed for renovating wastewater, a single set of water quality standards should apply to the tap, regardless of the source. The most difficult and yet unanswered question concerning reuse of wastewater for potable purposes is associated with health effects. Swayne *et al.*[120] surveyed U. S. cities with populations greater than 25 000 to determine how much wastewater and wastewater-derived material from discharges is present in surface water supplies. The results, from 525 cities, ranged from 142 utilities with no discharges identified to many utilities where the wastewater constituted a major portion of the water supply. Twenty cities with a total population of more than 7 million were determined to have surface water supplies containing 2.3 to 16% wastewater during average flow conditions, and 8 to 350% wastewater during low flow conditions. Okun[121] cautioned about the use of renovated wastewater for potable purposes and stressed that preventive health benefits, the benefits of acting before a catastrophe arises, should be paramount in our thinking. Source substitution, using renovated water for nonpotable uses while saving the highest quality sources for drinking water, should be used. Gaston[122] reviewed the subject of water quality criteria and standards for the use of reclaimed water for groundwater recharge, emphasizing the situation in California.

Parasites, bacteria, viruses. Since 1973 an epidemiological study of the direct consumers of renovated wastewater has been under way in Windhoek, South-West Africa (Namibia), the only location in the world where such consumption is occurring. The study design has been briefly described by Isaäcson *et al.*[123] and the epidemiological results thus far have been presented by Isaäcson and Sayed.[124] The renovated water has continued to meet all chemical and microbiological criteria for drinking water, and was supplied as an admixture with potable water from conventional sources only when needed because of water shortage. The study included waterborne infections, that is, gastroenteritis, enterovirus infections, and viral hepatitis, as well as water-related noncommunicable diseases, that is, cardiovascular disease and malignant neoplasms. The evaluation of gastroenteritis prevalence has shown a marginally lower incidence rate in people who consume the renovated water as compared with control groups. The findings of the studies in this epidemiological program are to be presented at a later stage.

Organics. Jekel and Roberts[125] pointed out that because of their potential health effects removal of halogenated organics in drinking water should be a major treatment objective in water reclamation. The most promising possibility for comprehensive, quantitative measurement is to determine the collective parameters of purgeable and nonpurgeable organic halogens. Relationships to specific compounds were presented. Zoeteman *et al.*[126] recommended the use of water taste assessment as a long-term water quality indicator, providing evidence that water taste has almost universal value as an indicator parameter of the presence of trace organics. The Denver water department's 4.4×10^{-2} m^3/s (1 mgd) potable reuse demonstration project was described by Work *et al.*[127] The health effects testing portion of the project will be implemented during the second year of operation, and will most likely consist of acute toxicity, mutagenesis, subchronic toxicity, teratogenicity, and chronic toxicity studies. The Los Angeles county sanitation districts' experimental scheme for evaluating the carcinogenic potential of renovated water groundwater recharge was described by Baird *et al.*[128] The procedures include organic residue extraction, mutagenic testing by Ames assay, HPLC fractionation of organic residues, and GC/MS/Computer compound analysis and molecular characterization of mutagenic fractions. The Ames test was used to examine recycled water from an Israeli wastewater reclamation project, involving groundwater recharge, by Neeman *et al.*[129] Lipophilic promutagenic activity was demonstrated, and the source attributed to either industrial or agricultural pollutants or products of microbial metabolism of the numerous organic compounds present in oxidation ponds. Denkhaus *et al.*[130] examined the removal of mutagenic compounds at the Stander wastewater reclamation plant in Pretoria, South Africa, by means of the Ames *Salmonella* assay. The results indicate that the concentration of mutagens was reduced during ferric chloride clarification with interstage chlorination, and during sand filtration and ozonation. Most of the mutagens detected were frameshift mutagens belonging to the groups of neutral organic compounds or organic acids

and phenols. Feeding experiments with rats failed to detect mutagens, and the low level of mutagens recovered by the Ames test compares favorably with conventional drinking-water supplies in the U. S. and South Africa examined by similar techniques.

Mutagenic and carcinogenic activity in conventional drinking water may be compared with that in renovated water. Complex mixtures of residue organic chemicals from drinking water samples of five U. S. cities were tested by Lang *et al.*[131] and shown to produce morphological transformation of mammalian cells, suggesting the presence of potentially carcinogenic compounds. Transfer of these cells to mice, and subsequent growth, showed them to be malignant. These results were consistent with dose-dependent positive Ames mutagenesis test results obtained previously on the same samples. Gruener and Lockwood[132] examined a freeze-dried sample of New Orleans tap water for mutagenic activity, using the Chinese hamster embryonic lung cell (V79) tissue culture. They found significant dose-related mutagenic activity after activation, and mutation promotion activity as well. Kraybill[133] evaluated the public health aspects of carcinogenic-mutagenic biorefractories in drinking water, and concluded that, although the toxicological and epidemiological evidence is inconclusive, there is serious concern about those contaminants. The ingested carcinogenic-mutagenic biorefractories may contribute to the total cancer burden; thus, control and reduction technologies in water treatment were recommended.

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